

Characteristics of Surficial Mass Movements on Cut Slopes of the Prime National Highway 1 (PNH-1) in Bhutan



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Abstract This article presents characteristics of surficial mass movements after cutting a slope through the Prime National Highway 1 (hereinafter abbreviated as PNH-1) in Bhutan. The surficial mass movement, in the form of slope failures, affects the ability of traffic to move along the PNH-1. The geology in the area of the PNH-1 consists of metamorphic rocks. There are several types of surficial mass movement in slopes, for instance, rock/soil slide, debris flow, and rock falls. Slope failure has occurred due to the geological discontinuities, the boundary of strata, joints, and so on. From the observation of more than 100 slope failures along the PNH-1, we classified the surficial mass movements into three types: “Denudation,” “Erosional flow,” and “Slide.” Among these three types, “Denudation” and “Erosional flow” destabilize the surface layer of the slope after a while after cutting, while “Slide” tends to collapse on the slope within a short time after cutting. According to Varnes’ landslide classification, surficial mass movements such as “Denudation” and “Erosional flow” are categorized as “Flows,” and “Slide” are categorized as “Slides.”

Keywords Surficial mass movement · Cut slope · Geological discontinuity

1 Introduction

This paper describes the characteristics of surficial mass movement as slope failures observed on the Primary National Highway 1 (hereafter referred to as PNH-1) in Bhutan. Surficial slope failures on the cut slope in Bhutan are mainly affected by the widening of the PNH-1. The slope failures are more concentrated in the rainy season between June and September. In Japan, over 70% of slope disasters are caused by surficial mass movements [1]. During slope observations on the PNH-1, we considered that more than 80% of slope disasters were due to the surficial mass movement. Therefore, they were not recognized as large-scale landslides during on-site observations. The ratio of the number of occurrences for the surficial mass movement is an

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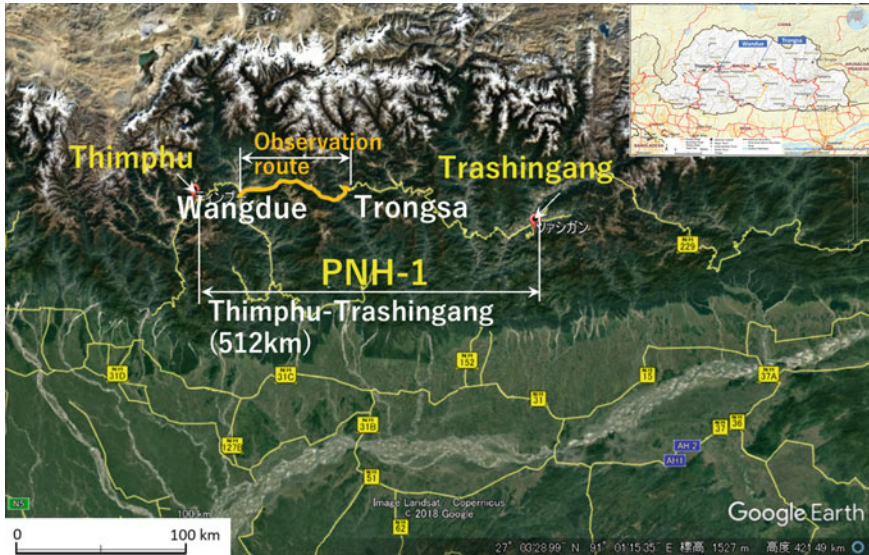


Fig. 1 Observed route (*Image Source* Google Earth)

interesting issue both in Bhutan and in Japan. The issue of surficial mass movements is a common problem and methods to prevent road disasters after cutting the slope is the same in both countries. In this paper, for the initial research focusing on the surficial mass movement, the typological classification of slope failures and the main factors for elucidating the mechanism of the surficial mass movements are discussed.

2 Investigated Slopes on the PNH-1

2.1 Investigated Slopes on the National Highway

The observed route for the cut slope is on the part of the PNH-1 between Wangdue and Trongsa heading east from the capital Thimphu (Fig. 1). The distance between the two towns of Wangdue and Trongsa is around 100 km.

2.2 How to Select Cut Slopes for Observation

The section observed for this project is a part of the PNH-1 from Wangdue (the Lobeyasa Regional Office) to Trongsa (the Trongsa Regional Office) where two regional offices of the Department of Road, Bhutan, are located. This section was

selected as it contains newly cut slopes due to widening of the road. For the selection of specific cut slopes, sites were selected using maps from the previous road works project, Google Earth images, and on-site observations of each cut slope.

2.3 Basic Features of the Investigated Area

Geological Setting. The investigation route has five units. The GHIm1 (Lower metasedimentary unit), the GHlo (Orthogneiss unit), the GHImu (Upper metasedimentary unit) in the Greater Himalayan Zone, the Pzc (Chekha Formation), and the Pzu (Maneting Formation) in the Tethyan Himalayan Zone from the lower level in geologic time (Fig. 2). The Greater Himalayan Zone consists mainly of metamorphic rocks originated in amphibole and granitic rocks, while the Tethyan Himalayan Zone consists mainly of metamorphic rocks that originated from sedimentary rocks.

Mass movements as slides with geological discontinuity on cut slopes are particularly likely to occur in granitic rocks of the GHlo and schist of the GHImu distribution areas.

Precipitation. Bhutan’s rainy season is from June to September. Data are shown for two towns, Wangdue and Trongsa, from 2015 to 2017 (Fig. 3a, b). In the four-month period from November to February of the following year, the monthly precipitation is almost always below 30 mm at the two sites.

Comparing the annual precipitation data between Wangdue and Trongsa, it is about 600 mm per year in Wangdue and 1500 mm per year in Trongsa. The annual precipitation in Trongsa is more than double that in Wangdue (Table 1). Moreover, in Trongsa, the rainfall exceeds 100 mm beginning in May (or April depending on the year) and continues until September. In Bhutan, the rainy season generally is from June to September. Precipitation data is consistent with this rainy season.

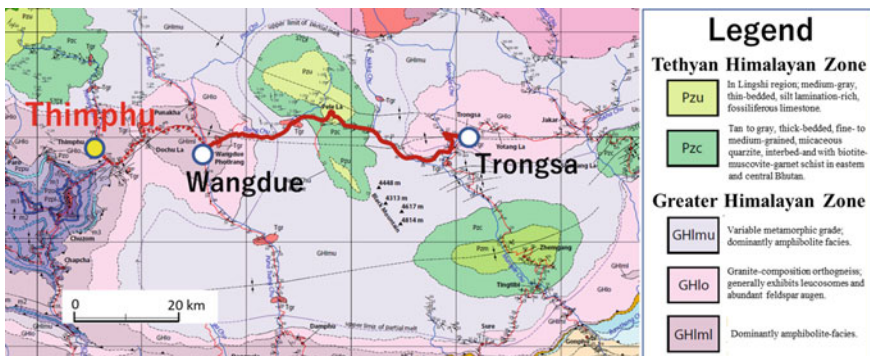


Fig. 2 Geologic map of the investigated area (modified from Long [2])

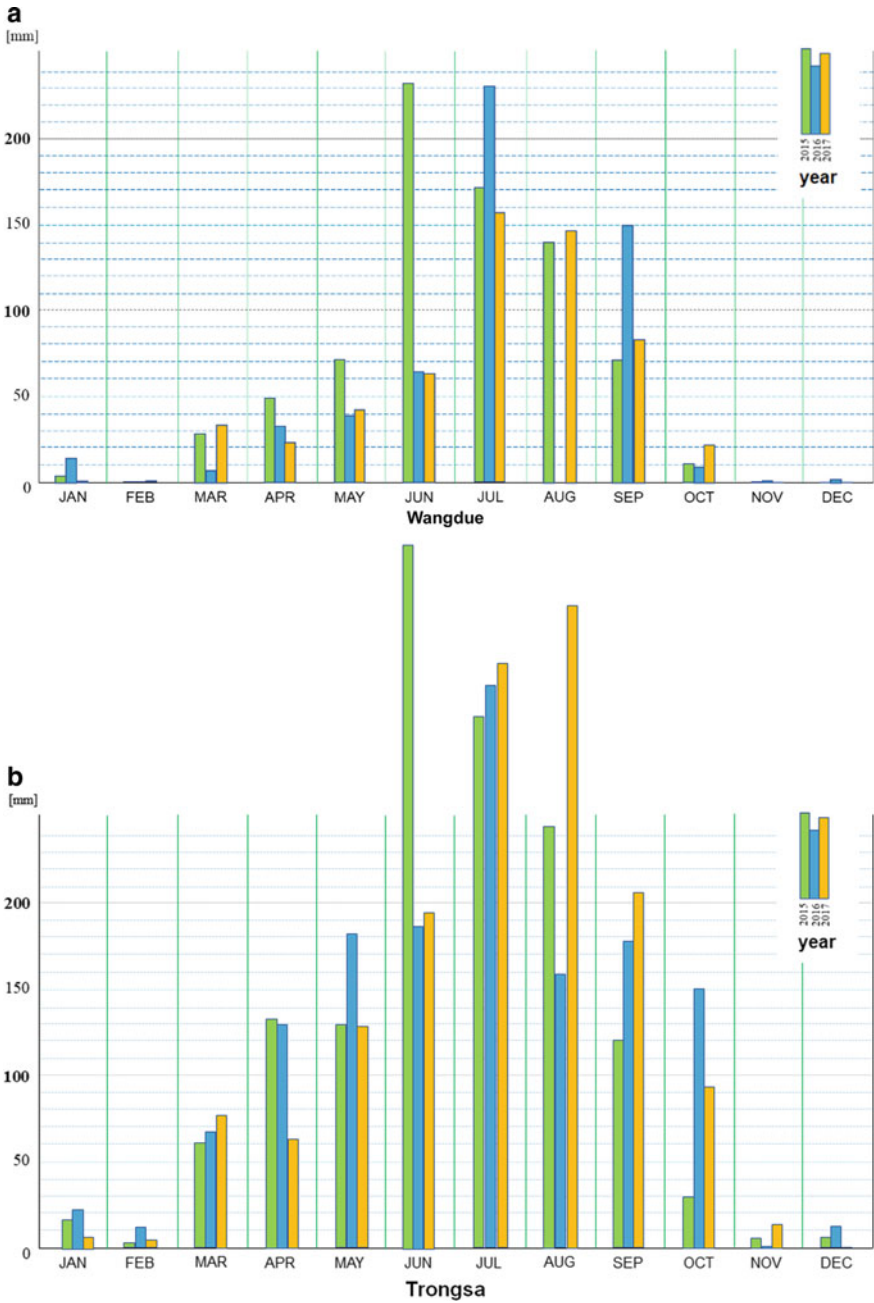


Fig. 3 a Precipitation graph for Wangdue, Bhutan (2015–2017). (Source Department of Roads in Bhutan: hereafter referred to as DoR data). b Precipitation graph for Trongsa, Bhutan (2015–2017) (Source DoR data)

Table 1 Precipitation data for Wangdue and Trongsa (2015–2017)

	Wangdue									Precipitation (mm)				
Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Sum	
2017	0.6	0.6	33.6	22.9	42	62.9	156	146.1	82.9	22	0	0	569.6	
2016	14.2	0	7.2	32.3	38.4	64	229.1	–	149	8.9	1	1.9	546+	
2015	4	0	28.6	48.8	71	230.7	170.5	139.1	71.1	10.7	0.1	0	774.6	
	Trongsa													
2017	6.6	3.9	76.4	62.9	127.6	194	337.5	371.1	204.3	92.9	13.5	0	1490.7	
2016	22.7	11.5	66.6	128.9	180.8	186.5	324.3	157.8	175.5	149.9	1.2	12.1	1418.9	
2015	17.1	2.5	60.3	132.2	128.3	406.4	306.6	243.7	119.5	29.5	5.6	5.9	1457.9	

Edited from the DoR source data

3 Results and Discussion

3.1 Classification of Surficial Mass Movement in Cut Slopes

Over 100 cut slopes have been observed in the observation section. For every 100 slopes observed, 26 sites will be classified as “Denudation,” 56 will be “Erosional flow” sites, and the remaining 16 will be “Slide” sites. The following are the three types of surficial mass movements in cut slopes based on the current PNH-1 observation results.

1. Denudation: Movement of surficial materials (Fig. 4a, b). There are three denudation processes: erosion, weathering, and mass wasting.
2. Erosional flow: Collapse of different geological boundaries or portions with different erosion resistance boundaries (Fig. 4c, d).
3. Slide: Sliding due to geological discontinuity such as joint, schistosity, and fault. Collapse from a stable base rock boundary regardless of soils or rocks (Fig. 4e, f). Slides are prominently observed in the granitic rocks and schist distribution areas along the PNH-1 in the study area.

3.2 Main Causes for Each Type of Slope Failure

Surficial mass movements are almost always related to geological discontinuity which becomes the boundary of sliding plane in Bhutan (Fig. 5). Of the kinds of geological discontinuities, the most common structures are observed are “bedding plane” and “schistosity” in Bhutan.

Denudation: Denudation occurs due to water from geological boundaries with different susceptibility to weathering with an example of this being between coarse-grained soils and fine-grained soils (Fig. 4a, b). As surface weathering progresses, it can be observed as surficial erosion and gully erosion on the slope.

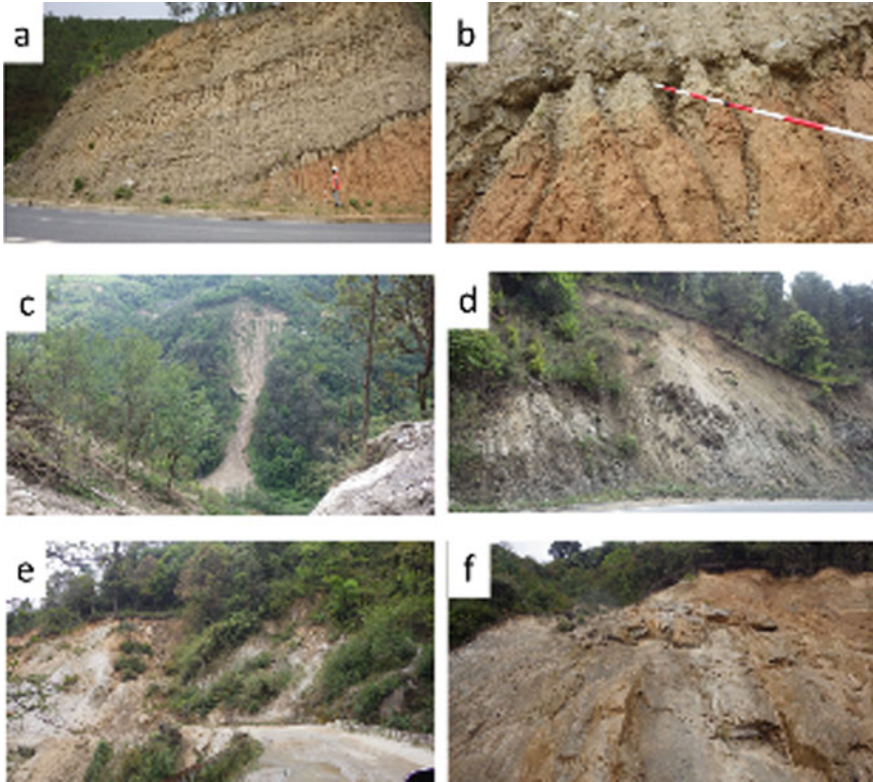


Fig. 4 Examples of slope failures on cut slopes (**a** Denudation, **b** Denudation (enlarged view of “a”), **c** Flow, **d** Erosional flow, **e** Slide (soils), **f** Slide (rocks))

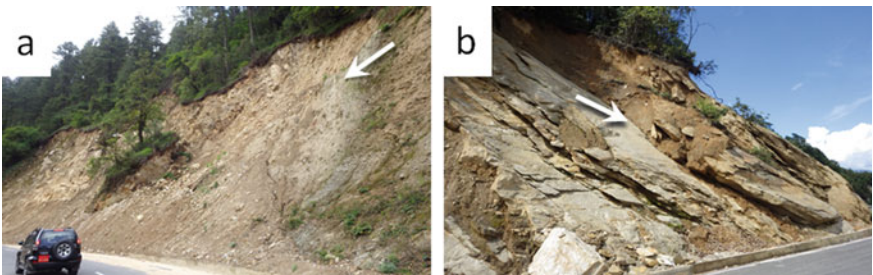


Fig. 5 Geological discontinuity on cut slopes (**a** Slide (soils), **b** Slide (rocks); white arrows: geological discontinuity)

Erosional flow: This occurs when materials mainly weathered from gneissose granite, deposit in the valley and flow down to the road due to precipitation (Fig. 4c). Materials on the slope move after weathering at the geological boundary. Also, materials weathered and/or deposited on the cut slope will move downward.

Slide: In the case of “Slide (soils),” we can find geological discontinuity between soils and rocks (Fig. 5a). The slip surface as geological discontinuity at “Slide (rocks)” slopes can be clearly seen (Fig. 5b). We found that geological discontinuities greatly affected to the slope failure on the cut slope at the sites observed in Bhutan.

Besides the classification of mass movement, it is important to define the relationship between stable and unstable slopes. By defining both Denudation and Erosional flow in the slope, it helps the government of Bhutan to plan which countermeasures to use against unstable slopes.

Observed geological boundaries and joints consist of geological discontinuities; however, it is not clear what the trigger point of slope failure is on geological discontinuity. In order to know which boundaries where Rock Slides and/or Soil Slides occur, it is necessary to recognize where the geological discontinuity is. Clarifying the cause and mechanism of slope failure and predicting the extent of damage will be important for future road maintenance and implementing slope countermeasures.

3.3 Correspondence with Varnes’ Landslide Classification

According to the typology of slope failures observed, “Denudation” and “Erosional flow” are included in “FLOWS” as the type of movement in Varnes’ Landslide Classification (Varnes 1978). Three types of surficial mass movements caused slope failure are “Denudation,” “Erosional Flow,” and “Slide” which classified into the two categories of “FLOWS” and “SLIDE” in the Varnes’ Landslide Classification (Table 2).

Surficial mass movement is almost included in “TRANSLATIONAL SLIDES,” on the contrary there are few “ROTATIONAL SLIDES” in cut slopes along the PNH-1 in Bhutan.

4 Conclusion

The type of surficial mass movement is divided into three types, “Denudation,” “Erosional flow,” and “Slide” which quickly causes instability due to cutting the slope.

Denudation is surficial erosion on the cut slope where it consists of talus and/or weathered soils. At first, the gully erosion occurs on slopes, and slope failure begins in small blocks. Erosional flow occurs at the cut slope where talus/detritus deposits on the slope and in the valley. A slide occurs in the rock slope with geological

Table 2 Abbreviated version of Varnes' Landslide Classification

Type of movement		Type of material		
		Bedrock	Engineering soils	
			Predominantly coarse	Predominantly fine
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slides	Rotational	Rock slide	Debris slide	Earth slide
	Traslational			
Lateral spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow	Debris flow	Earth flow
		(deep creep)	(soil creep)	
Complex		Combination of two or more principal types of movement		

surficial mass movements: yellow areas are modified from Jan Novotný [3]

discontinuities. Mainly, slides are prominently observed in the granitic rocks and schist distribution areas along the PNH-1.

The factors causing surficial mass movements consist of three key factors: “Geological discontinuity” as an inner factor, “Precipitation” as an outer factor under the natural force, and “Cut slope” as an outer factor due to road building (Fig. 6). The outer factor “Precipitation” influences all other surficial mass movements. The period affected by precipitation is during the rainy season from June to September. Furthermore, the combination of “geological discontinuity” and “cut slope” causes “Slide” in the short term, especially the rainy season.

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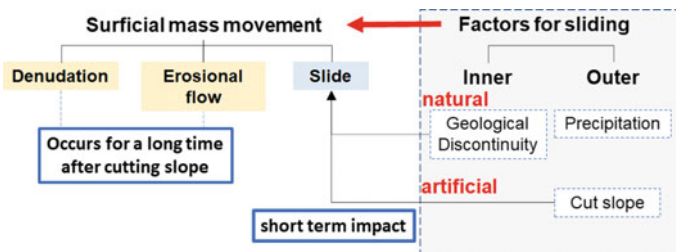


Fig. 6 Relationship between “surficial mass movement” and “factors for sliding”

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